



## Dose Distribution and Neutron Spectra Around a D-D Neutron Generator Using Bubble Detectors

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### Abstract

Neutron Radiation fields around a DD neutron generator at the Ontario Tech University neutron facility have been characterized. The facility is located in a heavily shielded room of 100 cm high-density concrete. The measured neutron spectra, as well as neutron equivalent dose rate, have been performed at 50 $\mu$ A and 120 kV. A series of experiments using a set of personal neutron bubble dosimeters as well as a neutron bubble spectrometer were carried out. An automatic bubble reader was used to count the number of bubbles. The measurements were performed at 90<sup>o</sup> relative to the neutron generator's central access and at distances ranging from 15 to 100 cm away from the neutron generator. The personal bubble dosimeter data agrees with the dose value measured with a tissue-equivalent proportional counter, however, the bubble spectrometer over-predicts the dose rate value.

**Keywords:** Neutron Generator; Neutron Dose; Bubble Detector; Neutron Spectra

## Introduction

Since their discovery, neutrons have played a pivotal and dynamic role in the fundamental study of matter structure as well as in various industrial applications. To meet the requirements for neutrons in different fields of basic research and nuclear applications, much effort has been devoted to the development of suitable neutron sources. As opposed to a nuclear reactor, neutron generators have been considered as a unique tool for a reasonable neutron flux at the desired time for research and industrial applications. Nowadays, advanced technologies allow having neutron generators with high neutron yield, different neutron energies, and a long operation lifetime. A DD neutron generator has been installed at Ontario Tech University as a tool for research and training in the nuclear engineering program at the faculty of energy systems and nuclear sciences.

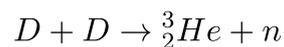
It was installed along with a 10Ci gamma irradiator at the Energy Research Center at the Ontario Tech University in Oshawa, Canada. The P-385 generator was operated with a high voltage of 150 kV and a beam current of 50  $\mu$ A. The energy of the emitted neutron depends on the energy of the accel-

In a previous paper, we reported the description of the facility and data evaluation of the neutron field around the neutron generator [1]. The current work aims to provide the spectral distributions of neutron emission as well as neutron dose rates in the vicinity of the neutron generator. A series of experiments have been carried out with a neutron bubble spectrometer as well as a set of neutron personal bubble dosimeters. The obtained experimental data have been compared with the measurement carried with a tissue-equivalent proportional counter [2].

## Experimental Setup and Methodology

### Neutron Generator Description

The neutron generator is a Thermo-Scientific P-385 D-D model that generates neutrons with an average energy of approximately 2.5 MeV from the following reaction:



erated deuteron and the angle of emission with respect to the deuteron ion beam direction. The neutron facility is hosted in a specifically shielded room surrounded by control rooms, and laboratories housing auxiliary support equipment. A top view of the facility is shown in Figure 1.

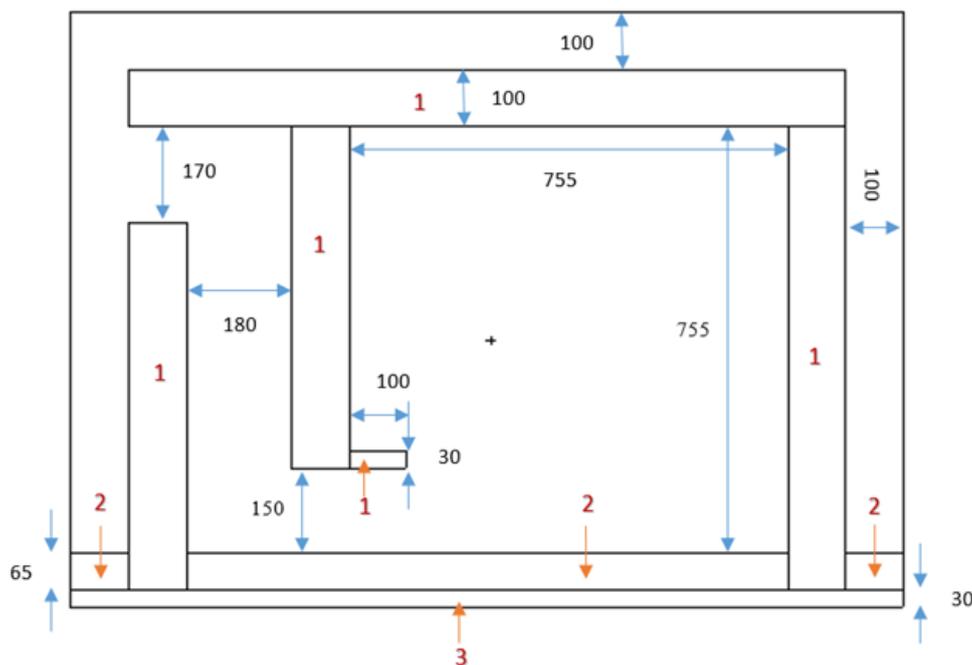


Figure 1: Top view of the neutron facility room (dimensions are in cm)

The generator is placed at the center of a 775 x 775 cm square room, with a height of 400 cm in the basement of the Energy Research Center building. Three of the four sides of the room are composed of heavy concrete of density  $3.8 \text{ g/cm}^3$ . All the heavy concrete walls are 100 cm thick. The side, backed with ground soil, has a wall constructed from ordinary concrete with a density of  $2.35 \text{ g/cm}^3$  [1].

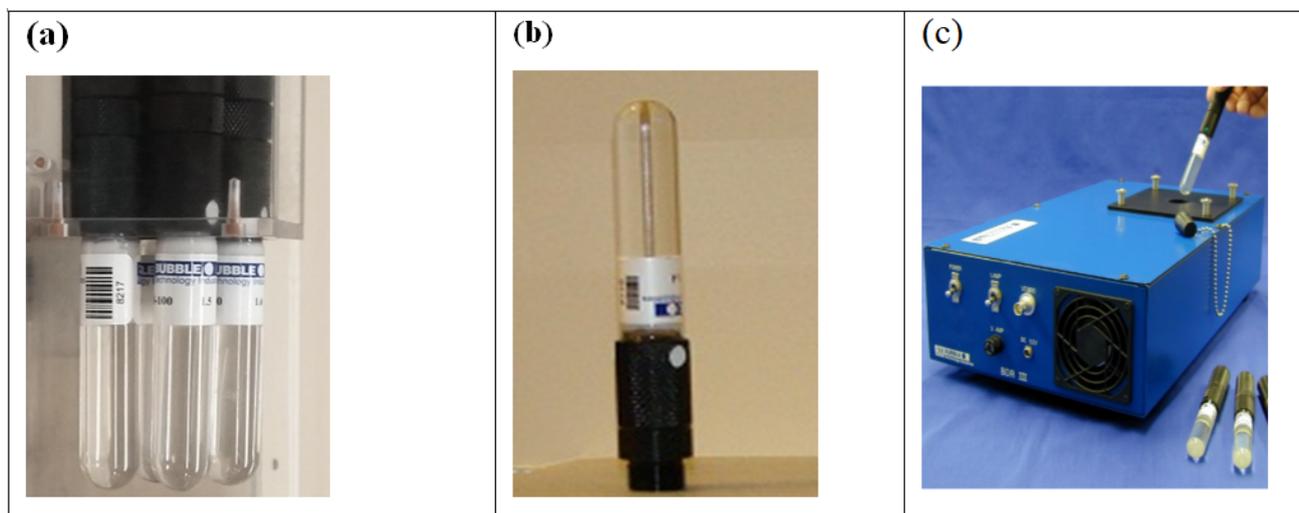
### Bubble Detectors and Bubble Reader

The bubble detectors used in this investigation were space type bubble detectors similar to those used in the space radiation research program aboard the International Space Station. Each detector has a 10 ml active volume with approximately  $10^4$  microscopic droplets, and a sensitivity ranging from 0.14 to 0.20 bubbles/ $\mu\text{Sv}$  [3]. The personal neutron bubble dosime-

ter referred to as PBD is a single-tube detector that produces visible bubbles when exposed to specific forms of radiation [3]. The neutron bubble detector spectrometer (NBDS) is a set of six bubble detector tubes referred to as BDS10, BDS100, BDS600, BDS1000, BDS2500, and BDS10000 [4]. Each of the BDS detectors has a neutron energy threshold for bubble formation as listed in Table 1. In a neutron spectrum measurement, all six bubble detectors are simultaneously exposed to the same radiation field. After irradiation, the number of bubbles in each of the six detectors is counted with the bubble reader. The number of bubbles is related to the fluence of neutrons above the minimum energy threshold for each detector. An automatic bubble reader was used to perform the bubble counting after each exposure. Both the detectors and the automatic reader, shown in Figure 2, were manufactured by Bubble Technology Industries (BTI).

**Table 1:** Characteristics of the bubble spectrometer [4]

Bubble spectrometer			Personal bubble dosimeter	
Name	Threshold, MeV	Sensitivity, bubble/ $\mu\text{Sv}$	name	Sensitivity, bubble/ $\mu\text{Sv}$
BDS10	0.01	0.19	PBD1	0.14
BDS100	0.1	0.12	PBD2	0.16
BDS600	0.6	0.19	PBD2	0.12
BDS1000	1	0.18		
BDS2500	2.5	0.13		
BDS10000	10	0.41		



**Figure 2:** (a) Bubble Spectrometer (b) Personal Bubble Dosimeter and (c) Bubble Reader

## Experimental Setup

The bubble detectors were exposed to neutrons of 2.5 MeV energy emitted at 90° relative to the axis of the neutron generator. A series of experiments have been carried out at different distances from 15 to 100 cm away from the neutron generator. The experimental setup is shown in Figure 3. For the personal neutron bubble dosimeter, the dose was obtained by di-

viding the number of recorded bubbles by the sensitivity of the detector, while for the neutron bubble spectrometer, the neutron spectra were extracted using the response matrix of the spectrometer which is a 6x6 matrix based on the six energy bins defined by the thresholds of the SBDS detectors. The matrix was obtained based on a series of data collected in different experiments. The unfolding techniques along with the value of the matrix entries were reported in [4].

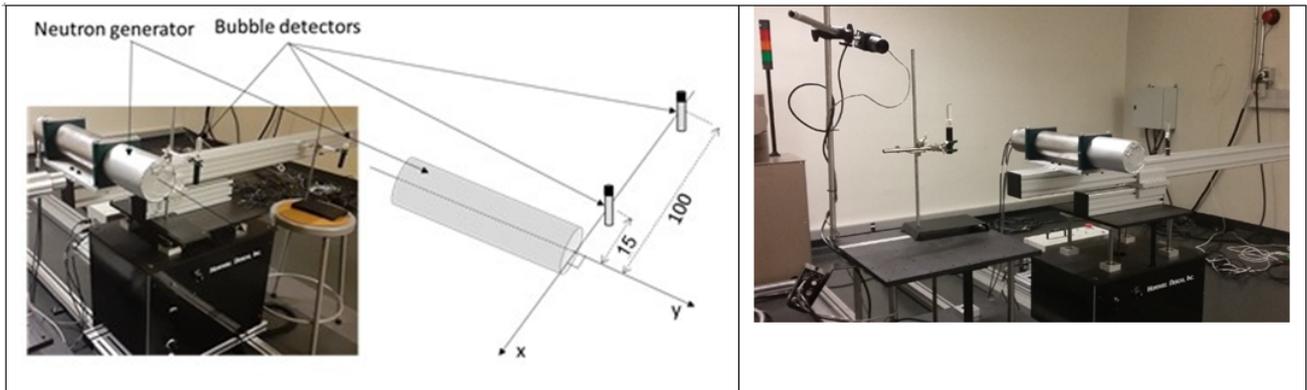


Figure 3: Experimental Setup

## Results and Discussion

The images of the six detectors of the spectrometer read by the bubble reader are shown in Figure 4(a). The bubble detec-

tor BD10000 does not show any bubbles since its threshold is 10 MeV and at 90°, the neutron energy is only 2.5 MeV. The remaining five bubble detectors show a different number of bubbles depending on their threshold and sensitivity.

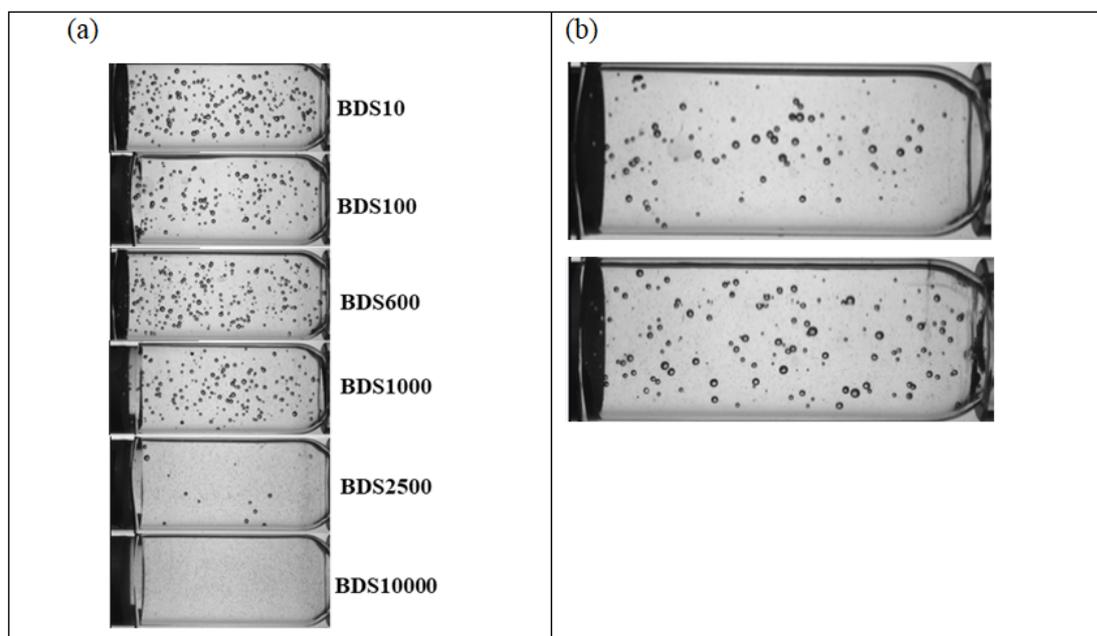


Figure 4: Images of the bubble spectrometer and two personal bubble dosimeters read by the bubble reader

The recorded number of bubbles in each tube was used along with the response matrix of the spectrometer and the neutron

spectra were extracted in six energy bins as shown in Figure 5.

One can see that the spectrometer predicts the 2.5 MeV peak of the neutrons emitted at  $90^\circ$ . There are some neutrons on

the left side of the peak due to the scattered neutrons from the surroundings.

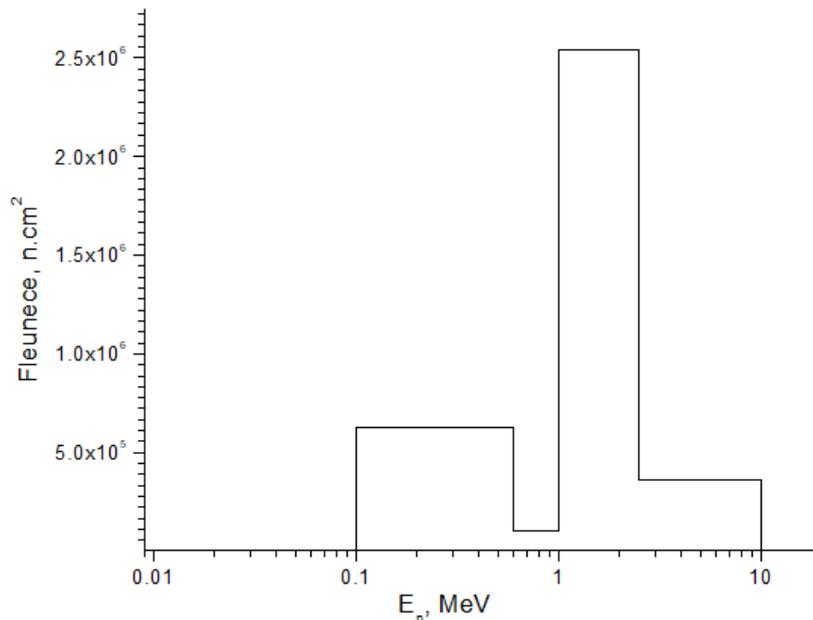


Figure 5: Spectral fluence measured with the bubble spectrometer

The dose rate was also extracted from the readings of the bubble spectrometer tubes and the data suggest that the bubble spectrometer overpredicts the dose rate. Such an overprediction may be due to the uncertainty in the response function matrix of the spectrometer.

Along with the bubble spectrometer, three personal bubble dosimeters were used in the experiments with different sensitivity ranging from 0.12 to 0.16 bubble/ $\mu$ Sv. All three dosimeters were simultaneously exposed to neutrons emitted at  $90^\circ$ . The images from the bubble reader of two bubble dosimeters are shown in Figure 6. The number of bubbles was counted and the neutron dose equivalent was extracted as a function

of the distance from 15 to 100 cm away from the central axis of the neutron generator. The dose value was averaged from the readings of all three detectors. The data were compared with those carried with a tissue-equivalent proportional counter reported in [2]. The obtained results are presented in Figure 7, and both data sets show a reasonable agreement. This investigation is a part of the characterization program of the facility to study mixed neutron/gamma radiation fields along with radiation detector development. Therefore, the confirmation of the dose rate, measured in the previous study at different distances, provides a quantitative value that can be delivered for testing the performance of other neutron devices under development.

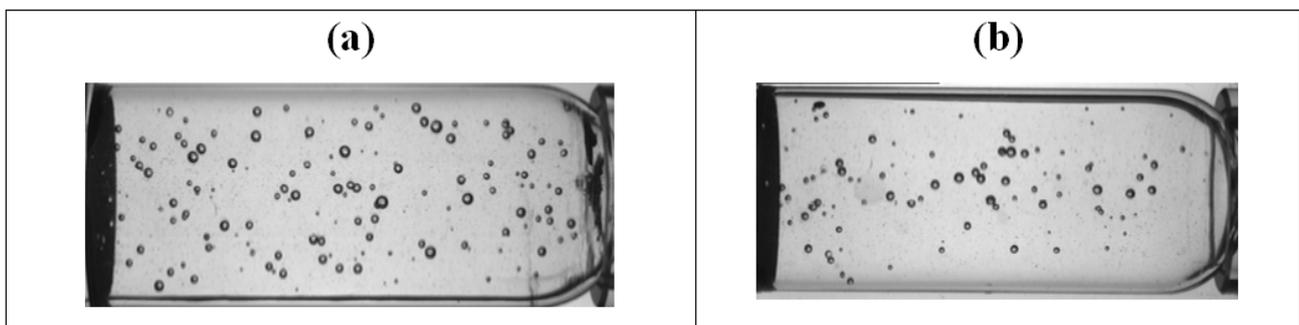


Figure 6: Bubble reader images of two personal bubble dosimeters used in the experiment (a) dosimeter with 0.16 b/ $\mu$ Sv and (b) dosimeter with 0.12 b/ $\mu$ Sv.

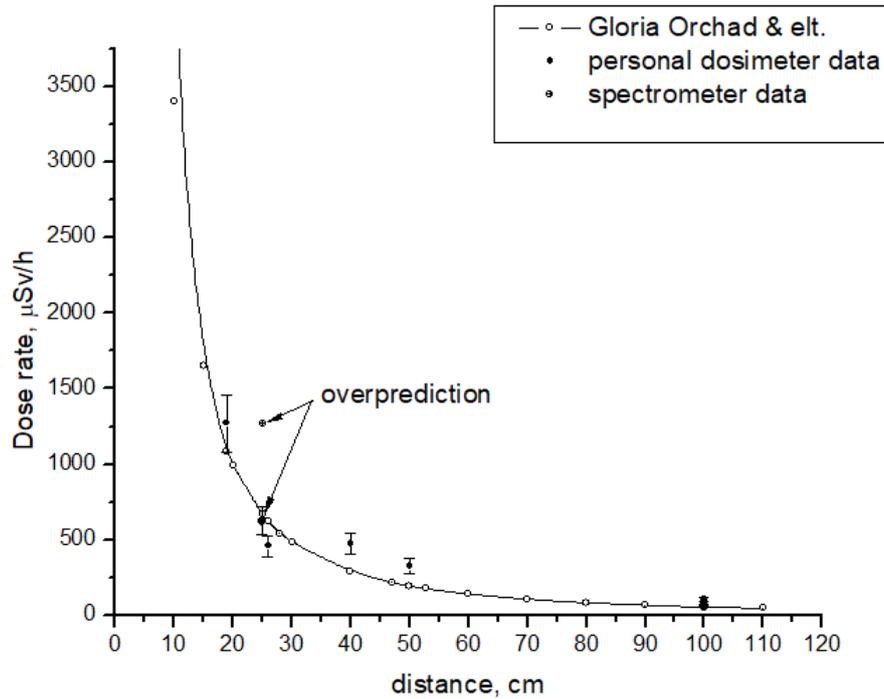


Figure 7: Dose equivalent rate as a function of distance

## Conclusion

Neutron fields at the Ontario Tech University neutron facility have been characterized. The DD neutron generator was operated at  $50\mu\text{A}$  and  $150\text{kV}$ . The neutron spectra and ambient dose equivalent rates with neutron energy of  $2.5\text{MeV}$  have been measured from 15 to 100 cm away from the neutron generator. Three personal bubble dosimeters and a bubble spectrometer were used in the experiments. The measured data

with personal bubble dosimeters were compared with a tissue equivalent proportional counter and both sets of data show a reasonable agreement. However, the bubble spectrometer overpredicts the dose rate value.

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